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SPATIAL VARIATION IN FISH AND INVERTEBRATE BYCATCHES IN A SCALLOP TRAWL FISHERY

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ABSTRACT One of the biggest problems faced by fisheries management is the issue of bycatch and discards. The target species of fisheries are often found in association with other organisms. Despite attempts to reduce bycatch through technical modifications, the indiscriminate nature of many fishing gears means that nontarget species become incidental catch or bycatch. This study assessed the spatial variation across four fishing grounds in the composition of bycatch of an otter trawl scallop (*Aequipecten opercularis*) fishery in the Irish Sea. The results showed that the percentage of bycatch in the fishery as a whole was relatively low at 7.42 ± 0.52 by weight of the total catch. In 2012, the total bycatch for the fishery was estimated to be 309 tonnes compared to landings of queen scallops of 2,410 tonnes, landed by Manx trawlers either to the Isle of Man or United Kingdom. Significant differences were found between the four fishing grounds in relation to mean catch by weight, mean bycatch by weight, and bycatch species composition; however, there was no significant difference found in diversity and species abundance among the four fishing grounds. The results demonstrated that fishing ground was the dominant factor controlling bycatch variation within this fishery, which was related to some extent to water depth. The findings of the study indicate that understanding variation in bycatch in relation to the characteristics of different fishing grounds would enable fishermen and managers to manage (minimize) bycatch through the use of temporary spatial management measures.

KEY WORDS: bycatch, scallop, trawl fishery, discards

INTRODUCTION

The majority of fisheries in North Atlantic waters are multispecies in nature due to the association of the target species with other organisms. Nontarget species become incidental catch or bycatch when they cannot be avoided through technical or spatial management measures. Bycatch is broadly defined as the incidental catch of the nontarget marine animals and undersized individuals of target species (Crowder & Murawski 1998, Garcia et al. 2003, Davies et al. 2009). Discards consist of organisms of commercial and noncommercial value that are caught and returned to the sea that may be alive, dead, or damaged (Catchpole et al. 2005a). Discarding occurs for a variety of reasons including the fish caught may be below minimum landing size, the bycatch may have little or no market value, and the catch may be damaged or high graded (i.e., lower valued individuals or species discarded to maximize profits), or the quota for a species may have been reached (Clucas 1997). A number of other factors can also affect the capture of bycatch and the practice of discarding, such as complex technical (Stratoudakis et al. 2001a, Marie-Joelle & Trenkel 2005), social (Catchpole et al. 2005b), economic (Alverson & Hughes 1996, Pascoe1997, Catchpole & Gray 2010), and legislative factors (Rochet et al. 2002). The relative importance and effect of each of these factors on the rate of bycatch or discarding varies considerably between different species, vessels, métiers, and fleets, and will also vary temporally (Catchpole & Gray 2010) and spatially (Rochet et al. 2002). The levels of bycatch and discarding are also affected by the choices of individual fishers, in deciding how and where to fish, as well as which portion of the catch to retain and which to discard (Catchpole et al. 2005b, Catchpole & Gray 2010). In Europe, however, discarding of quota species will be banned by 2019, with the aim of encouraging fishermen to innovate to avoid generating bycatches and hence reduce/eliminate discarding practices. While technical innovations to eliminate bycatch will have an important role to play in reducing bycatch, understanding spatial and temporal variations in patterns of the occurrence of bycatch species would provide fishermen with the important insights to avoid bycatches and the costs associated with having to retain and land these species.

Seasonal variation in the amount, diversity, and species composition of discards has been demonstrated in a number of fisheries (Liggins & Kennelly 1996, Trujillo & Pereda 1997, Machias et al. 2001, Stratoudakis et al. 2001a). Discards also vary geographically. For example, Murawski (1996) found that species composition and diversity were a significant function of location, whereas Bergmann et al. (2002) found significant differences in bycatch composition between samples from the north and south Clyde Sea areas. Understanding the relationship between environmental characteristics and the occurrence of bycatches would help to identify "bycatch hot spots," i.e., areas or periods with high discard rates (Perkins & Edwards 1996). The latter studies can inform management options to prevent high bycatch and discarding through the use of technical measures or the use of seasonal or area closures.

Scallop fisheries in the United Kingdom are the third most economically important fishery and are prosecuted with either dredges (king scallops and queen scallops) or otter trawls (queen scallops). The most important queen scallop fishery in

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the United Kingdom is located in the northern Irish Sea and primarily within the territorial waters of the Isle of Man. In 2011, 4,529 tonnes of queen scallops with a first sale value of £1,390,000 (MMO 2011) were landed into the Isle of Man, with a similar amount landed into other UK ports. Given the importance of this fishery to a primarily rural economy, it is important to understand the spatial and seasonal variation in the bycatch and potential discard of commercially important species of fish (e.g., cod and whiting) in this fishery. The purpose of the present study was to quantify the composition of bycatch of the otter trawl queen scallop (*Aequipecten opercularis*) fishery in the Isle of Man territorial sea using observer data from commercial vessels. Variation in bycatch was examined to identify key parameters [spatial (fishing grounds) and environmental (depth, temperature, and chlorophyll-*a*)] that might explain patterns in bycatch abundance and composition. Understanding these relationships would inform management measures or technical innovation to reduce discards in this fishery.

MATERIALS AND METHODS

Sampling

Sampling was conducted aboard seven commercial fishing vessels from June 25 to August 26, 2012, during the course of their normal fishing activities. The trawl-based queen scallop fishery tends to start in mid-June and ends in mid-October. Fishing took place in the four most important queen scallop fishing grounds colloquially known as Targets, Douglas, Chickens, and Ramsey, which are located within the territorial waters of the Isle of Man (Fig. 1). Specific sampling locations were geolocated using a handheld differential Global Positioning System with the start and end points of the tows recorded. The swept area per tow was calculated from dimensions of

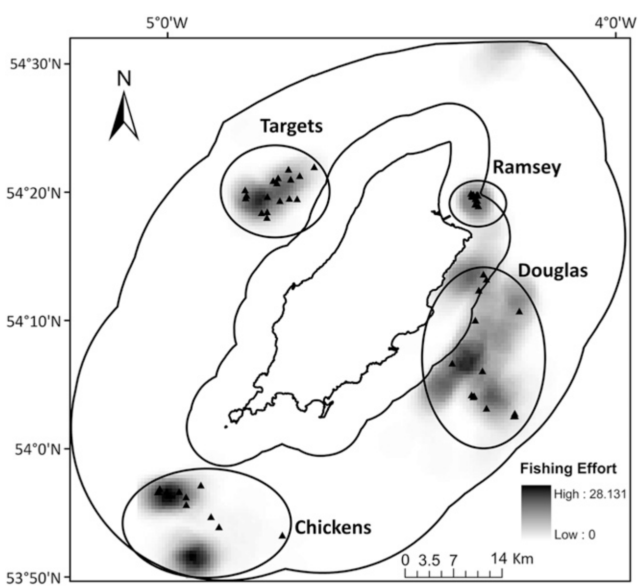

Figure 1. Fishing effort (h·km^{-2}) around the Isle of Man by otter trawlers from June to October 2012. Data are derived from vessel monitoring systems reporting positions every ~2 h. Speeds of <1.1 and >3.5 knots were excluded. Points (▲) indicate start position of tows included in the analysis. The boundaries of the fishing grounds used in this study, and the 3 and 12 nautical mile limits are also shown.

a vessel's gear and the tow data, using the method described by Courtney et al. (2007).

$$\text{Area swept} = \frac{F \times \text{NSF} \times D}{10,000} \tag{1}$$

where F is the footrope length (meters), NSF the net spread factor [0.75 (Sterling 2005)], and D the distance trawled (converted to meters using one nautical mile = 1,852 m). Using the swept area, catches were standardized to number of organisms caught per hectare.

A total of 58 tows were sampled: 16 from Targets, 15 from Douglas, 14 from Chickens, and 13 from Ramsey (Fig. 1). The fishing gear used in this fishery was a single rockhopper otter trawl. The catch was sorted on deck through the use of a mechanical riddle consisting of fixed diameter steel rings and bars. Queen scallops above the minimum landing size (>55-mm shell height) were retained, whereas undersized queen scallops and bycatch were typically discarded overboard. All vessels in the fishery used a mesh size of no less than 80-mm diamond mesh.

To calculate the abundance and composition of bycatch as a component of a typical commercial catch, the catch was sorted on deck removing all teleost fish and elasmobranchs. Because of the large size of the commercial catch, for taxa other than fish and elasmobranchs, a subsample of mean (±SE) weight 38.03 ± 0.74 kg was removed to quantify the composition of the invertebrate bycatch. These subsamples were weighed and divided into target species (queen scallop *Aequipecten opercularis*), bycatch species, and debris. All bycatch was identified to species level whenever possible, and the number and wet weight of individuals were recorded. To calculate the weight of discarded (undersize) queen scallops as a proportion of the total catch, the total weight of queen scallops in the subsample was recorded, these were then passed through the rotating scallop sieve, and the weight of the retained queen scallops were recorded. The number of bags of retained queen scallops (each bag contained approximately 40 kg) per tow was also recorded. Using the total catch of queen scallops for the entire season (data provided by the Department of Environment, Food and Agriculture, Isle of Man Government), the total bycatch for the entire fishery was estimated. This was done using the percentage of bycatch to catch for each of the four areas.

To calculate the weight of undersized queen scallops in the total catch of queen scallops the following formula was used:

$$\text{QU}_\text{t} = \left(\frac{\text{QR}_\text{t}}{\text{QR}_\text{s}}\right)\text{QU}_\text{s} \tag{2}$$

The weight of invertebrate bycatch in the total catch was calculated as follows:

$$I_\text{t} = \left(\frac{\text{QR}_\text{t}}{\text{QR}_\text{s}}\right)I_\text{s} \tag{3}$$

where QR is the weight of retained queen scallops for a tow (t) or a subsample (s), QU the weight of unretained queen scallops, and I the weight of invertebrate bycatch. All weights are expressed in kg. The number of invertebrate individuals in the subsample was multiplied by the invertebrate weight proportion I_t/I_s to give an estimate of the number of individuals in the tow.

Abiotic and Habitat Variables

The mean water depth for each tow was derived from depths recorded while onboard and then tidally corrected. Seabed habitat type was determined during a habitat survey conducted in 2008, which classified the habitats surrounding the Isle of Man into 40 different biotopes (White 2011). Daily satellite-derived estimates of sea surface temperature (SST) were extracted from the 6-km Global High Resolution Sea Surface Temperature dataset, and chlorophyll-*a* values were extracted from 1-km level 3 images of ocean color measured by the Moderate Resolution Imaging Spectroradiometer sensor (data provided by North American Electric Reliability Corporation Earth Observation Data Acquisition & Analysis).

Comparisons of Bycatch

To test whether the mean biomass and abundance of bycatch differed across fishing grounds, a one-way analysis of variance (ANOVA) was used to compare the mean number of individuals and biomass of the bycatch (number per hectare) between fishing grounds. The data were checked for homogeneity of variance using Levene's test, and if this assumption was not met, an appropriate transformation was applied to the data. If the transformed data still did not meet the necessary assumptions, then nonparametric tests were used (Kruskal–Wallis (K-W) followed by pairwise Mann–Whitney *U*-tests). This procedure was applied throughout this study for univariate analyses. The bycatch abundance data including all species were used to examine differences in species diversity between fishing grounds. Species diversity was calculated using the Shannon–Wiener index and Simpson's dominance index.

The bycatch abundance data were then separated into invertebrate and vertebrates (teleosts and elasmobranchs), because of the different methods of sampling used for each of these groups. Once separated, the abundances for each species were ranked in terms of their percentage contribution to the total abundance of all species. To remove any statistical bias caused by rarer species (which may not be sampled adequately), those species that contributed to less than 0.5% of the total abundance were excluded (Zuur et al. 2010). Data were initially square root transformed and clustered using the Bray-Curtis index of similarity to compute the level of similarity between samples. The Bray-Curtis resemblance matrix was used to produce multidimensional scaling (MDS) ordination plots of bycatch data. Pairwise analysis of similarities (ANOSIM) testing was used to determine differences in the composition of bycatch between fishing grounds. Similarity percentage (SIMPER) analysis was used to determine which species contributed most to the similarity within fishing grounds and the dissimilarity between fishing grounds. The individual species identified by SIMPER that accounted most for the dissimilarity between fishing grounds were then analyzed in greater detail using univariate tests (ANOVA or K-W).

Water depth, SST, chlorophyll-*a* concentrations, and habitat type for each tow were related to the grouping of abundance data using the BEST routine to explore which environmental variables contributed most to any patterns observed within the biological data.

RESULTS

Bycatch Abundance and Composition

The total bycatch for the entire fishery over the entire season including all fishing grounds was estimated to be 309 tonnes for Manx vessels in the 2012 open season. The percentage weight of bycatch compared with target species catch across all four fishing grounds was estimated to be 7.42%. For catches of the target species, the mean weight per hectare was significantly different for both retained queen scallops ($F_{3,54} = 5.66$, $P = 0.002$) and unretained queen scallops ($F_{3,54} = 4.51$, $P = 0.007$) between fishing grounds, such that Douglas had the highest mean weight of retained scallops and Ramsey the highest weight of unretained scallops (Table 1).

Significant differences were observed in the mean bycatch biomass between fishing grounds (K-W, $\chi^2 = 53.20$, $P < 0.023$). Figure 2A shows that the mean (±SE) bycatch biomass was highest in Douglas (10.07 ± 1.49 kg), which differed significantly from Targets (5.05 ± 0.57 kg); however, no other significant differences were found between any other areas. The highest mean (±SE) bycatch abundance was found in Douglas with 285.44 ± 56.86 individual bycatch organisms per hectare swept, and the lowest mean (±SE) abundance was found at Chickens with 121.66 ± 13.54. Despite this, there was no significant difference in bycatch abundance between fishing grounds (K-W, $\chi^2 = 3.21$, $P = 0.360$).

Bycatch Composition

The composition of bycatch differed between the four fishing grounds both in terms of mean weight and species composition.

TABLE 1.

Mean (± SE) biomass (kg) and percentage per hectare of retained queen scallops, unretained queen scallops, and total bycatch in each of the four fishing grounds.

	Chickens	Douglas	Ramsey	Targets
Biomass				
Retained queen scallops	70.45 ± 8.48	84.88 ± 6.08	52.90 ± 5.73	52.19 ± 6.0
Undersized queen scallops	34.77 ± 6.03	84.88 ± 4.12	35.67 ± 4.84	12.49 ± 1.41
Bycatch	5.97 ± 0.54	10.11 ± 1.50	5.94 ± 0.96	5.40 ± 0.63
Percentage				
Retained queen scallops	64.43	73.45	57.14	72.96
Undersized queen scallops	28.97	18.14	36.56	18.94
Bycatch	6.60	8.41	6.30	8.11

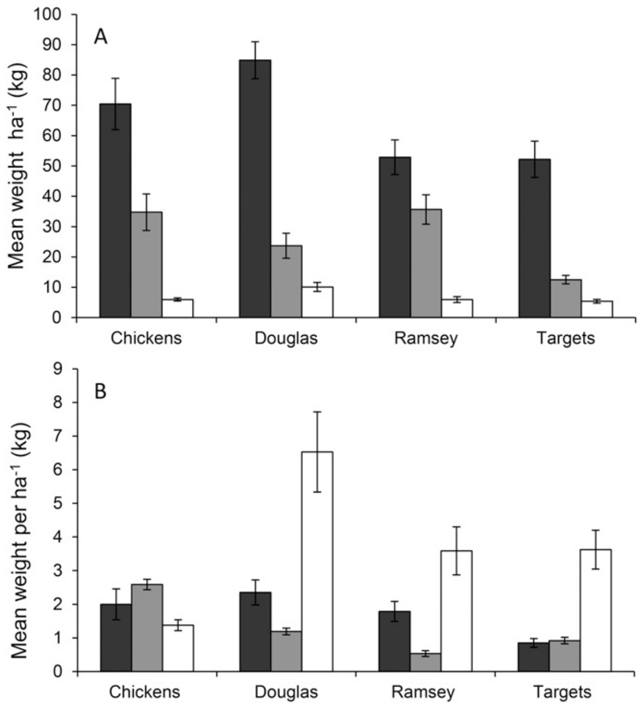

Figure 2. (A) Mean weight per hectare (±SE) of retained queen scallop (black), unretained queen scallop (gray), and total bycatch (white) for each of the four fishing grounds. (B) The mean weight per hectare (±SE) of the bycatch at each of the four fishing ground locations for elasmobranch (black), teleost fishes (gray), and invertebrate (white) taxa.

The mean weight per hectare of teleost fish, elasmobranchs, and invertebrates all differed significantly between fishing grounds (teleosts: $F_{3,54} = 11.16$, $P < 0.001$; elasmobranchs: $F_{3,54} = 4.16$, $P = 0.01$; and invertebrates: K-W, $\chi^2_3 = 21.34$, $P < 0.001$) (Fig. 2B). The highest mean (±SE) weight for teleost fish was found in Chickens (2.59 ± 0.16 kg) (Fig. 2B). Although there was an overall difference in mean (±SE) elasmobranch bycatch weight between areas, the only pair that showed a significant difference was between the Douglas (2.35 ± 0.37 kg) and Targets (0.85 ± 0.13 kg) areas. The mean (±SE) weight of invertebrates was highest in Douglas (6.53 ± 1.19 kg), which was significantly higher than that of the Chickens (1.38 ± 0.16 kg) area, whereas the mean weight in Ramsay and Targets differed significantly from Chickens but do not differ from Douglas (Fig. 2C). Neither the Shannon–Wiener diversity index ($F_{3,54} = 0.261$, $P = 0.853$) nor Simpson's dominance index ($F_{3,54} = 0.154$, $P = 0.927$) showed any significant differences among the fished grounds.

Invertebrate Bycatch Assemblages

Although there was some overlap in the composition of invertebrate bycatch among the different fishing grounds, the differences were found to be significant (Figure 3A, ANOSIM, $R = 0.432$, $P = 0.001$). Table 2 shows the results of univariate analyses for the species accounted most for the differences between fishing grounds. All these species apart from *Alcyonium digitatum* showed a significant difference between fishing grounds (Table 2, Figure 4). The fit between the environmental variables and the patterns of similarity observed among the invertebrate bycatch data were weak ($\rho = 0.285$ for depth with SST). Depth had the best fit of any single environmental variable ($\rho = 0.272$). Hence, the benthic invertebrate bycatch for each area may reflect the catchability of different species that occur in those areas rather than their association with environmental characteristics.

Fish and Elasmobranch Bycatch Assemblages

The MDS plot shown in Figure 3B revealed significant differences in fish and elasmobranch bycatch assemblages between fishing grounds (ANOSIM, $R = 0.544$, $P = 0.001$). Multivariate pairwise ANOSIM tests showed that there were significant differences between all fishing grounds. The species that contributed most to the similarity in fish and elasmobranch bycatch assemblages within fishing grounds and the average similarity of each of the grounds is shown in Figure 5. The average similarity within each of the fishing grounds shows little variation, with Chickens having a slightly higher similarity (69%) than the other fishing grounds, followed by Ramsey (68%), then Douglas (66%), and finally Targets (63%).

Table 2 shows the results of univariate analysis of the fish and elasmobranch species that accounted most for the differences between fishing grounds as ascertained from the SIMPER analysis. All but three species tested showed significant differences in abundance between fishing grounds. There was no significant difference between fishing grounds for the abundance of *Scyliorhinus canicula*, *Limanda limanda*, and *Pleuronectes platessa* (Table 3).

The BEST analysis showed that depth had the best fit (though weak) to the similarity among tows based on the fish abundance data ($\rho = 0.335$).

DISCUSSION

Bycatch Abundance and Composition

During this study, bycatch expressed as a percentage of the total queen scallop fishery catch was estimated as 7.42 ± 0.52, which although significantly higher, is reasonably close to value of 3.36% reported by Duncan (2009). Irrespective of the minor differences reported in this and the latter study, the percentage of the catch that is bycatch is low when compared with many other fisheries in the region. Borges et al. (2005) estimated the percentage of discards in the Irish Sea (ICES division VIIa) for the Irish beam trawl fleet was 67% of the total catch and 25% in the otter trawl fleet that targeted *Nephrops norvegicus*. The *N. norvegicus* trawl fishery in the Clyde in the west of Scotland has a reported mean discard rate of 62% (Bergmann et al. 2002). There are few comparable scallop fisheries that use trawl nets as most scallop fisheries are fished using dredges. The Argentinean Patagonian scallop (*Zygochlamys patagonica*) fishery, however, uses otter trawls; the rate of bycatch by weight relative to the quantity of target species caught is not known; however, the gear is considered to be relatively nonselective, and the efficiency was estimated to range between 21% and 31%, which would imply that the bycatch would be around 69%–79% (Lasta & Iribarne 1997). In the Canadian Georges Bank, dredge fishery for *Placopecten magellanicus* bycatch was estimated at a level of 6% (DFO 2007, 2008), whereas in the Queensland otter trawl fishery that includes saucer scallop (*Amusium balloti*) and mud scallop (*Amusium pleuronectes*), the annual bycatch was estimated at 25,000 tonnes compared with the landed catch of 10,000 tonnes, which means that

TABLE 2.

ANOVA/K-W tests performed on indicator invertebrate and fish and elasmobranch species identified from SIMPER analysis, also shown are the *P* values of post hoc tests.

			Post hoc					
Species	**F/χ^2**	**P**	**C, D**	**C, R**	**C, T**	**D, R**	**D, T**	**R, T**
Invertebrates								
Alcyonium digitatum	1.896	0.141	0.113	0.805	0.383	0.547	0.885	0.916
Ophiura sp.	6.969	**<0.001**	**0.043**	0.420	0.328	**0.001**	0.711	**0.010**
Ophiothrix fragilis	11.887	**0.008**	0.652	0.105	**0.015**	0.052	**0.009**	0.232
Psammechinus miliaris	18.237	**<0.001**	**0.016**	**<0.001**	**0.001**	0.254	0.953	0.075
Ascidiacea	5.460	**0.002**	1.0	**0.008**	0.144	**0.008**	0.153	0.550
Archidoris pseudoargus	7.895	**<0.001**	**0.005**	**0.007**	0.999	1.00	**0.005**	**0.007**
Diodora graeca	32.517	**<0.001**	<0.001	0.519	1.00	**0.002**	**<0.001**	0.503
Hydroid	8.562	**0.036**	0.085	0.488	0.411	**0.015**	0.338	0.132
Inachus dorsettensis	3.182	**0.031**	0.993	0.776	0.077	0.606	**0.035**	0.485
Suberites domuncula	16.714	**0.001**	**0.037**	**0.009**	0.951	0.294	**0.017**	**0.004**
Asterias rubens	28.253	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.071	0.747	0.405
Crossaster papposus	27.083	**<0.001**	**0.001**	0.325	0.759	**0.005**	**<0.001**	0.170
Buccinum undatum	23.952	**<0.001**	**0.005**	1.00	0.580	**0.006**	**0.011**	0.589
Fish and elasmobranchs								
Scyliorhinus canicula	2.469	0.072	0.764	0.996	0.410	0.884	0.049	0.285
Limanda limanda	0.785	0.508	0.992	0.700	0.583	0.828	0.723	0.999
Eutrigla gurnardus	3.670	**0.018**	0.728	0.177	0.991	**0.012**	0.867	0.084
Melanogrammus aeglefinus	20.443	**<0.001**	0.050	**<0.001**	**<0.001**	0.101	0.086	0.928
Microstomus kitt	35.088	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.004	0.066	**<0.001**
Pleuronectes platessa	6.099	0.107	0.650	**0.029**	**0.041**	0.132	0.232	0.650
Aspitrigla cuculus	14.015	**<0.001**	0.909	**0.001**	**<0.001**	0.004	**<0.001**	0.680
Trigla lucerna	5.052	**0.004**	0.405	0.206	0.955	0.929	**0.008**	0.060
Merlangius merlangus	15.710	**<0.001**	**<0.001**	0.144	0.867	**0.021**	**<0.001**	**0.020**
Callionymus lyra	3.116	**0.034**	0.263	0.984	0.179	0.130	0.994	0.083
Liophius piscatorius	20.443	**<0.001**	0.050	**<0.001**	**<0.001**	0.101	0.086	0.928
Trisopterus minutus	9.364	**0.025**	0.308	0.186	0.717	0.779	0.119	0.072

All tests had 3 and 53 degrees of freedom. Letters of post hoc tests identify fishing grounds C = Chickens, D = Douglas, R = Ramsey and T = Targets. Bold values show significant *P* values.

discards accounted for approximately 71% of the total catch (Robins & Courtney 1998).

The catch composition varied significantly between the four sea areas sampled around the Isle of Man. Trawl catches from Douglas and Targets had on average the highest percentage of retained queen scallops (73%) and the highest percentage bycatch of nontarget species (8%). In contrast, catches from Ramsay had the lowest percentage of retained queen scallops (57%) but also the lowest bycatch of nontarget species (6%). Such variation is perhaps not surprising given observations in other studies (Hutchings 1996, Walters 2003, Poos & Rijnsdorp 2007, Rijnsdorp et al. 2011).

In terms of biomass per hectare, all three components of the catch differed significantly between fishing grounds; therefore, where a vessel chooses to fish may impact on their efficiency and the amount of bycatch caught. During the 2012 season, our

Figure 3. MDS plots of (A) invertebrate and (B) fish and elasmobranch bycatch assemblages within the four different fishing grounds based on Bray–Curtis similarity of square root–transformed abundance data from 58 tows conducted as part of this survey.

TABLE 3.

Mean abundances (±SE) per hectare of the invertebrate and fish and elasmobranch bycatch species that caused the highest dissimilarity between fishing ground taken from SIMPER analysis.

	Chickens	Douglas	Ramsey	Targets
Invertebrates				
Alcyonium digitatum	30.47 ± 8.39	112.52 ± 34.8	49.26 ± 17.64	59 ± 21.93
Ophiura	13.37 ± 3.92	3.30 ± 0.89	20.73 ± 5.23	6.97 ± 1.84
Ophiothrix fragilis	9.61 ± 3.75	37.78 ± 24.05	1.35 ± 0.44	0.69 ± 0.34
Psammechinus miliaris	1.21 ± 0.49	19.08 ± 5.14	57.87 ± 25.25	24.74 ± 11.86
Ascidiacea	15.70 ± 3.76	13.47 ± 2.74	3.19 ± 1.50	6.81 ± 1.97
Archidorispse udoargus	8.43 ± 4.21	0.82 ± 0.43	0.94 ± 0.53	5.24 ± 0.96
Diodora graeca	–	10.51 ± 3.28	0.35 ± 0.24	–
Hydroidea	4.69 ± 2.51	0.56 ± 0.45	7.65 ± 2.77	3.61 ± 1.93
Inachus dorsettensis	3.95 ± 1.54	0.11 ± 0.11	6.18 ± 1.49	3.32 ± 1.14
Suberite domuncula	0.48 ± 0.34	2.58 ± 0.86	5.23 ± 1.74	0.29 ± 0.17
Asterias rubens	1.99 ± 0.43	31.38 ± 4.49	19.12 ± 4.26	24.56 ± 2.47
Crossaster papposus	0.17 ± 0.17	8.09 ± 2.27	0.58 ± 0.28	–
Buccinum undatum	–	4.90 ± 1.47	–	0.32 ± 0.24
Elasmobranch and teleost fish				
Scyliorhinus canicula	2.6 ± 0.62	3.26 ± 0.57	2.51 ± 0.47	1.39 ± 0.24
Limanda limanda	2.41 ± 0.88	1.98 ± 0.49	1.18 ± 0.23	1.14 ± 0.25
Eutrigla gurnardus	0.39 ± 0.09	1.22 ± 0.40	0.20 ± 0.09	0.5 ± 0.14
Melanogrammus aeglefinus	3.73 ± 0.72	0.29 ± 0.29	–	1.42 ± 0.40
Microstomus kitt	2.28 ± 0.36	0.26 ± 0.08	–	0.53 ± 0.11
Pleuronectes platessa	0.77 ± 0.15	1.88 ± 0.55	0.30 ± 0.07	0.33 ± 0.06
Aspitrigla cuculus	3.32 ± 0.58	2.73 ± 0.37	1.13 ± 0.33	0.68 ± 0.13
Trigla lucerna	0.15 ± 0.04	0.42 ± 0.08	0.34 ± 0.07	0.13 ± 0.05
Merlangius merlangus	1.53 ± 0.59	0.08 ± 0.04	0.42 ± 0.11	1.80 ± 0.41
Callionymus lyra	0.09 ± 0.06	0.23 ± 0.06	0.07 ± 0.03	0.24 ± 0.08
Liophius piscatorius	0.20 ± 0.04	0.09 ± 0.03	0.02 ± 0.01	0.02 ± 0.01
Trisopterus minutus	0.14 ± 0.08	0.08 ± 0.08	–	0.37 ± 0.22

results suggest that Douglas was the preferred fishing ground, which was also supported by vessel monitoring system data. The abundance of queen scallops in the different fishing grounds in Manx waters, however, varies considerably from year to year (Murray & Kaiser 2012), and therefore the preferred fishing ground is likely to change with each fishing season. As a largely recruitment-dependent fishery, it would be expected that the focus of the fleet effort would move depending on where the last good settlement occurred. Hence, understanding bycatch composition in the different fishing grounds has important management implications as the fishery moves from one location to another.

Bycatch Composition

Not only the overall catch composition but also the species composition of the bycatch was different between areas. The bycatch in Chickens by weight was predominantly teleost fish (45%), with the second and third largest components being elasmobranchs and invertebrates at 28% and 27%, respectively. In the three other fishing grounds, the dominant component of the bycatch was invertebrates, and in both Douglas and Ramsey, the second largest component by weight was elasmobranchs followed by fish.

Invertebrate Bycatch Assemblages

The invertebrate bycatch obtained in tows differed according to the location of the tow. The MDS analysis revealed clear patterns in invertebrate bycatch assemblages, with distinct pattern in community composition between fishing grounds. The ANOSIM further revealed that these patterns were significantly different, with each fishing ground showing a distinct community composition, all with high levels of similarity within fishing grounds and dissimilarity between fishing grounds. Some species identified as causing similarity within fishing grounds such as *Alcyonium digitatum*, hydroids, Ascidiacea, and *Diodora graeca* are known to be associated or occur as epibionts on queen scallops in the Isle of Man (Bradshaw et al. 2003). Similarly, scallop spat have been reported to settle on hydroids and bryozoans that are considered important for scallop recruitment (Eggleston 1962, Brand et al. 1980, Dare & Bannister 1987), so their common presence on queen scallop fishing grounds is not surprising. During this study, *A. digitatum* and *D. gracea* were commonly observed attached to the shells of queen scallops.

Despite the clear differences observed in invertebrate bycatch abundances between fishing grounds, none of the environmental variables investigated as part of this study showed a high level of correlation. Because of the nature of sampling on commercial fishing boats, it was not possible to record parameters such as temperature, chlorophyll-*a*, and habitat type *in situ*, with water depth being the only environmental variable recorded at the time of sampling. The inherent inaccuracies arising from the use of remotely sensed data may have masked any potential environmental relationship. It was expected that habitat type would influence invertebrate abundance assemblages. Habitat type however, was assigned according to data taken from a prior study (White 2011) that assigned habitat types to 0.25-km^2 cells corresponding to

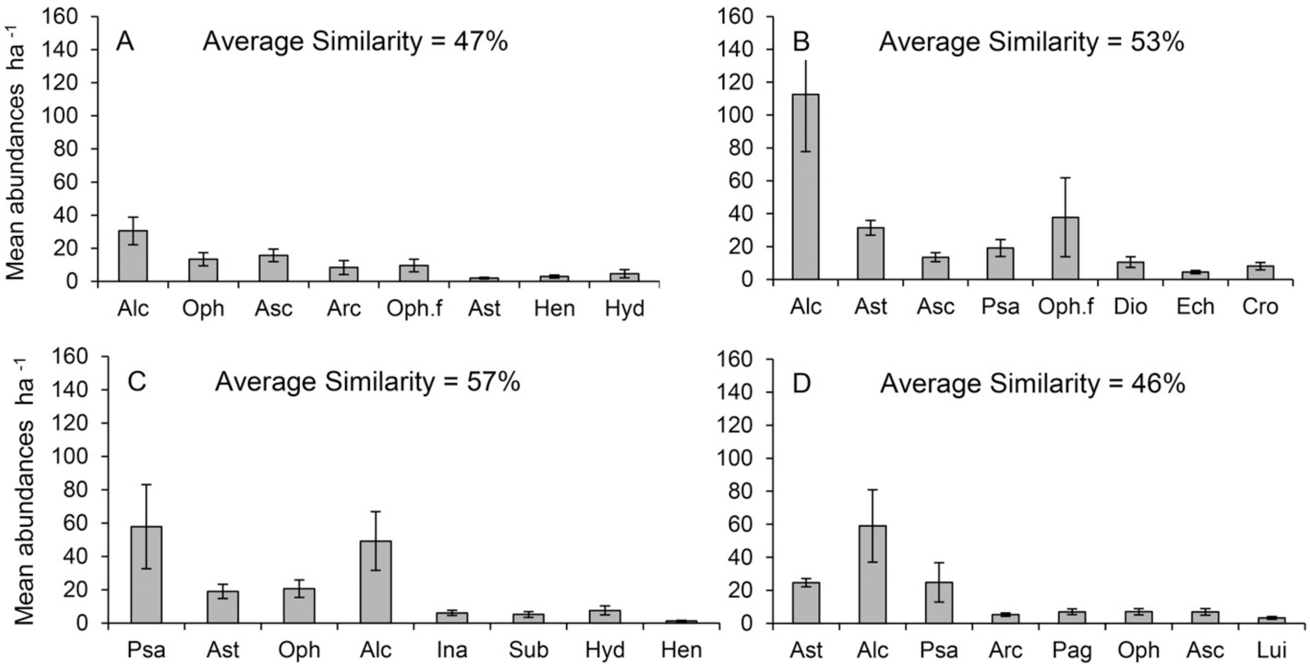

Figure 4. Mean abundance (±SE) of the invertebrate species that contribute most to the similarity among samples at each of the four fishing grounds (A) Chickens, (B) Douglas, (C) Ramsey, and (D) Targets, which were identified by SIMPER analysis. The average percentage similarity within each of the fishing grounds is also given. Alc = *Alcyonium digitatum*, Asc = Ascidiacea, Arc = *Archidoris pseudoargus*, Ast = *Asterias rubens*, Cro = *Crossaster paposus*, Ech = *Echinus esculentus*, Hen = *Henricia sanguinolenta*, Hyd = Hydroidea, Ina = *Inachus dorsettensis*, Lui = *Luidia ciliaris*, Nem = *Nemertesia* spp., Psa = *Psammechinus miliaris*, Oph = *Ophiura* spp., Oph.f = *Ophiura fragilis*, Pag = Pagurus prideaux, Sub = *Suberites domuncula*.

community group identified from the nearest survey station, which were located on a 5-km grid throughout the Manx Territorial Sea. The habitat type categorization was therefore at a relatively coarse resolution compared with the samples collected during this study.

Depth was the single factor (measured in this study) that was correlated to bycatch community composition, although the correlation was very low. These results imply that depth (and other autocorrelated variables) has some influence on the

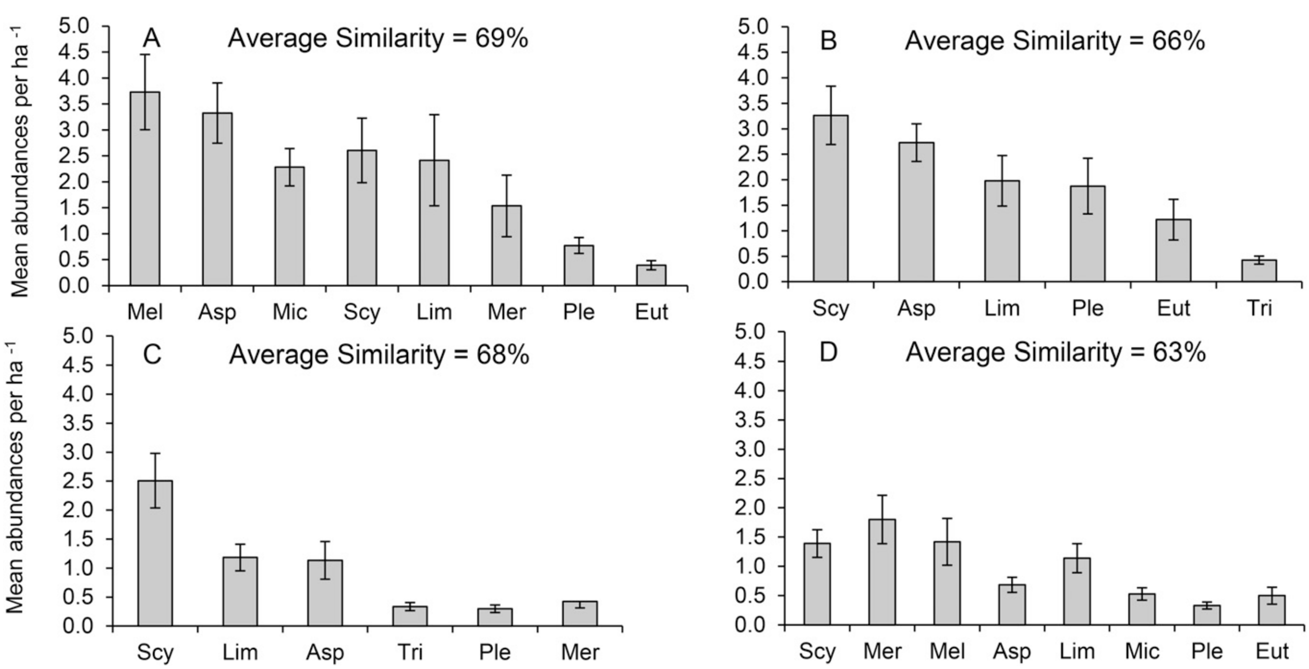

Figure 5. Mean (±SE) abundance of the fish and elasmobranch species that contribute most to the similarity among samples at each of the four fishing grounds (A) Chickens, (B) Douglas, (C) Ramsey, and (D) Targets taken from the outcome of a SIMPER analysis. The average percentage similarity within each of the fishing grounds is also given. Asp = *Aspitrigla cuculus*, Eut = *Eutrigla gurnardus*, Lim = *Limanda limanda*, Mel = *Melanogrammus aeglefinus*, Mer = *Merlangius merlangus*, Mic = *Microstomus kitt*, Ple = *Pleuronectes platessa*, Scy = *Scyliorhinus canicula*, Tri = *Trigla lucerna*.

invertebrate assemblages. It is well known that depth influences species assemblages, and a number of studies have found that depth influences invertebrate bycatch assemblages (Probert et al. 1997, Bergmann et al. 2002).

Fish and Elasmobranch Bycatch Assemblages

Fish and elasmobranch species assemblages showed similar patterns to that of invertebrate species assemblages. There were clear distinctions between fishing grounds, with no two fishing grounds being the same. In addition each fishing ground showed a distinct community composition, with high levels of within group similarity.

Furthermore, there appears to be a clear separation between samples from Douglas and Ramsey, and Chickens and Targets (Fig. 3B). Douglas and Ramsey had a similar set of species that contributed most to the makeup, with spotted catshark (*Scyliorhinus canicula*), red gurnard (*Aspitrigla cuculus*), and dab (*Limanda limanda*) being the highest contributing species in both fishing grounds. The top four contributing species on Chickens were haddock (*Melanogrammus aeglefinus*), red gurnard, lemon sole (*Microstomus kitt*), and spotted catshark, whereas on Targets catshark, whiting (*Merlangius merlangus*), haddock, and red gurnard were spotted. Despite significant differences between all fishing groups, it would appear that there is some grouping of the fishing grounds. These results indicate that geographic location is the biggest factor influencing fish and elasmobranch assemblages, as Douglas and Ramsey are on the east coast of the Island and Chickens southwest and Targets west. These patterns in fish bycatch assemblage have been seen in other studies. Bergmann et al. (2002) found significant differences between the north and south of the Clyde sea area in Scotland, in this study the differences were also attributed to differences in depth.

Understanding the spatial variability in catches of sensitive species such as elasmobranchs or commercially important fish species provides important insights to inform the appropriate scale at which to monitor uptake of quota in relation to discards. As in many other areas of the United Kingdom, the Isle of Man has a producer organization that leases quota on behalf of its members. Given appropriate monitoring of bycatch, and the use of technical innovations to fishing gear technology, the producer organization would have the potential to implement their own management in partnership with its members, such as real-time voluntary closures of areas that are most prone to generating undesirable bycatch.

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